the material accummulated, having value to the expert engineer and corroboratory of those conclusions. In the opinion of the writer, the latter may be accepted as thoroughly well-established.

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ON CERTAIN PHYSICAL DIFFICULTIES IN THE CONSTRUCTION OF LARGE GUNS.

THE substitution of forged steel for cast iron in gun construction has resulted in the universal adoption of the built-up gun. About the year 1855 the Englishman, Blakely, and the American, Treadwell, independently discovered and demonstrated the value of the principle of initial tension as a means of increasing the strength and economizing the material of a gun. What this means can be briefly shown.

Assume a tube of perfectly annealed metal with given tenacity and elasticity. If a powerful stress be applied, there is no reason why one part should be more capable of resisting it than another. Let the tube be closed at one end, and let the stress originate from within near this end, as in the explosion of a charge of gunpowder. Under this condition it was shown by Treadwell that if we assume the tube to be made up of a large number of uniform, cylindrical, concentric layers of metal, then the resistance of each layer to the exploding force will vary inversely as the square of the diameter. The stress in its effect upon the metal decreases at a rate quite similar to that of the radiation of heat or light. If the wall of the tube be under no initial stress its inner surface may be stretched even to its elastic limit, while the stretching of the outer surface is comparatively slight. The metal's property of elastic resistance is hence not utilized to the best advantage in the outer layer, while in the inner layer it may be utilized to an extent inconsistent with safety.

Treadwell therefore proposed a plan of gun construction which has since been universally adopted. The modern gun consists of a steel tube which is reenforced by one or more concentric hoops or tubes, the number and position of these being adjusted to the variation of pressure from within as the hot exploding gas finds vent at the muzzle. The ordinates of the pressure curve are greatest at the origin, this being taken as the middle of the seat of the powder charge in the chamber. They decrease rapidly with approach to the muzzle. The reenforcement of the tube should therefore be greatest around the breech. A tubular jacket is shrunk on around the main tube, covering the breech and often as much as two-thirds of the entire length. Around the jacket is a series of compressing hoops, and around this there may be a second or outer series of supplementary hoops. Originally the interior diameter of the jacket is a little less than the exterior diameter of the tube. By heating the jacket sufficiently it is made to expand until large enough to be slipped into place over the cold tube. This becomes enormously compressed by the subsequent cooling of the jacket. In like manner the first hoop is too small to be slipped over the cold jacket until sufficiently heated for this purpose. The same remark applies to the relation between the second and first hoops. The final result is that the diameters of the tube, both external and internal, are permanently decreased by the compression of the jacket, while those of the hoops are permanently increased. Their contractile force is not enough to compress the jacket into smaller space, for this itself is pushed outward by the powerful reacting force of the compressed tube within. The hoops, therefore, serve to reenforce the jacket by their own tendency to contract. Having been put on in an expanded condition and prevented from recovering their normal dimensions,

they continue in a permanent condition of tension.

Steel is the only metal that combines elasticity and tenacity in such high degree as to warrant its advantageous use in the manner just described. For gun metal the material should be manganese steel, made from the purest wrought iron attainable, with a very small percentage of carbon, indeed not more than one per cent. This should be so uniformly diffused as to secure the closest possible approach to absolute homogeneity. The elastic limit should not be reached for any stress under 50,000 pounds per square inch, nor should the ultimate strength be less than 100,000 pounds per square inch. Such steel withstands a high temperature without softening, resists erosion well, and permits but little set under shock beyond the elastic limit. The preparation of such metal is a severe test of skill for the metallurgist. The most conspicuously successful gunmaker in the world, Friedrich Krupp, of Essen, Germany, uses crucible steel exclusively for this purpose. This firm, founded by the grandfather of its present head, has made a specialty of steel and its applications in manufacture during the last eighty-five years. Bessemer, open-hearth, and crucible steel plants are all included in its outfit. Much the most expensive product among these is crucible steel. In its manufacture the skill of the fathers has been given to their sons; and doubtless grandsons and great-grandsons will continue to apply the secrets of their special art in the same place. With the staid conservatism of the laboring classes in Germany the development of heredity in artisan skill is not uncommon. In America so restless, impatient and ambitious are our laborers that the son rarely ever lives in the same place or works at the same occupation with his father.

So highly developed is the crucible steel industry at Essen that ingots of this metal weighing each as much as seventy tons have been repeatedly cast, and with these the forgings are made from which Krupp constructs his monster guns. Many visitors at the Columbian Exposition looked with astonishment at the great gun weighing one hundred and twenty tons, which was only one of several of the same size due to this firm. In other parts of the world crucible steel is abundantly produced for cutlery, and for small articles generally where the finest quality is demanded. But nowhere else than in Essen has the highest grade of crucible steel been made thus far in quantities sufficient for the largest forgings. In England, in France, and in America gun metal is at present made by the open hearth process. While this product is greatly superior to Bessemer steel the method of production is such as to forbid the attainment of such nearly perfect homogeneity as can be secured by the more expensive crucible method.

The open hearth steel used for our largest American guns is produced for the most part, if not entirely, at Midvale and Bethlehem in Pennsylvania. Before actual use test specimens are required to manifest tensile strengths from 75,000 to 125,000 pounds, and elastic limits from 40,000 to 70,000 pounds, per square inch, according to the calibre of the gun and the special parts of this for which the metal is intended. For tubes, jackets and hoops the maximum tensile strength demanded is 93,000, and the maximum elastic limit, 53,000 pounds per square inch.

Up to ten years ago American fortifications were for the most part supplied with nothing superior to the Rodman cast-iron smooth-bore columbiad and Parrott rifle, the latter being made of cast iron but reenforced with a wrought-iron hoop. During this interval Congress has appropriated about $20,000,000 for the modernizing of our navy and our seacoast defences. For

the latter the largest built up steel rifle thus far constructed has been one of 12-inch caliber, 40 calibers in length, weighing 57 tons. This is not yet ready for use. A 16-inch rifle, very nearly as massive as the great Krupp gun, has been ordered and will probably be finished within the next two or three years. A number of 12-inch 34-caliber guns have been finished, tested and mounted.

In assembling the parts of the large 40-caliber gun, at the Watervliet Arsenal gun shop a few months ago, an unfortunate mishap occurred. After the tube had been reenforced near its forward end with a series of hoops it was prepared for the more formidable work of shrinking on the large jacket. It was stood up vertically upon the breech end, and the heated jacket was let down into position. The heating proved to be insufficient to secure all the expansion needed, and as a result the cooling jacket gripped the tube before quite reaching the final position intended. An interesting problem was now presented, that of separating the tube and jacket after they had become thoroughly cool, and completing the process which had been so unexpectedly interrupted.

After due consideration the plan which seemed most promising of success was to introduce the cold gun, with breech downward, as suddenly as possible into a furnace, protecting the exposed part of the tube below the jacket from the heat by enclosing it in a bag of asbestos cloth through which a strong blast of cold air should be propelled. The jacket being thus heated first, while the tube within was comparatively cool, it was hoped that expansion enough might be attained to ensure separation. In order to keep the greatest possible difference of temperature between jacket and tube, a flow of cold water through this was set up immediately after its emplacement within the furnace. The breech had been closed water-tight. A pipe occupying the axis of the bore was coupled at the top with hose from an elevated tank full of ice water, and this was carried thus to the bottom. After it had filled the tube it was carried off by an overflow pipe. The jacket, or certainly its lower part, was quickly raised to a temperature estimated to be about 1100° F. The temperature gradients from outer to inner surface would obviously be curves, at first sharply concave upward, but gradually approaching straight lines as the heating continued. It was hoped that, before the equilibrium expressed by the straightening of these gradients should set in, the jacket would become expanded enough to settle down by its own weight into the desired final position.

But this hope was doomed to disappointment. The external heating and internal cooling was continued nearly eight hours on January 27th, the flow of ice water being kept quite uniformly forty cubic feet per minute. Its temperature was raised from 34° to 40° F. in transit, with but little variation after the first two hours. The water was then discontinued and the supply of heat kept up through the night. On the following day the experiment was renewed, but varied by trying the effect of sudden cooling from within. On admitting the supply of ice water there was naturally much steam produced at first, but within fifteen minutes the temperature difference between inflow and outflow fell to 36°. At the end of two hours it had fallen to 9°, and during the remaining six hours it continued quite uniformly about 8°. This difference was in excess of that of the previous day, as it had been found necessary to reduce the rate of water supply. This experiment being unsuccessful, the gun was removed from the furnace and allowed to cool.

The furnace had been originally con-

structed of such dimensions as to permit of heating the longest jacket, but not an entire gun. Since the breech and unjacketed part of the gun under present conditions had to occupy space within the furnace, an extension of this at the top had to be improvised to enclose the upper part of the jacket. Soon after the experiment began it was observed that the heating was by no means uniform, and by no supplementary efforts could uniformity be secured.

Measurement upon the cooled gun revealed the fact that the jacket had changed its position nearly half an inch, but this was only one-twentieth of the shifting needed. It was not surprising also to find that the whole assemblage was perceptibly warped.

The method, applied on so large a scale and under conditions which had precluded the possibility of uniform heating, had failed. But theoretically it seemed unassailable. It was decided to test it again under more favorable conditions. The construction of a new large gun for this test would obviously involve an unwarranted expense; for the cost of a completed 12-inch gun of this type is not much less than $60,000. A short 'dummy' gun was therefore constructed, of 8-inch bore and 3 feet in length. This was provided with hoop and jacket, which were shrunk on tightly into position, a special furnace being built for the purpose of the experiment. The piece was inserted into the hot furnace, the water turned on to the interior, and at the end of 3 minutes the jacket suddenly dropped 4 inches. It continued then creeping downward at a moderately uniform rate, and dropped entirely off from the tube at the end of 42 min. 30 sec. The temperature of the inflowing water was 58° F. and that of the outflow 67° F., no attempt being made to secure artificial cooling by use of ice.

The success of this experiment, which was made on the 31st of March, caused the decision to make another trial with the large gun. This was started on May 11th, extra precautions being taken to secure uniformity of heating. An auxiliary grate had been prepared for the furnace extension above, and with a view to securing the highest heat as close to the jacket as possible baskets of heavy wire netting were filled with charcoal, inserted in the furnace and brought close up around the gun after its insertion. At the same time water at a temperature of 68° F. was turned on, as it had been found impossible to secure a sufficiently rapid supply of ice. The elevation of temperature in transit was at first 5° F., and this rose in time to 11° F. At the end of 22 h. 30 min. the jacket having remained immovable, the fire was drawn from the furnace, while the water supply was continued 15 hours longer, until the gun was thoroughly cooled.

It is but due to say that, although this experiment has proved an instructive failure, the gun is not lost to the ordnance department of the government. The unjacketed part of the breech will be cut off, and the final outcome will be simply a gun somewhat shorter than provided for in the original specifications.

But the question may be asked, will this gun be so reliable as it would have been without passing through so many fiery ordeals? After each furnace trial it was carried back to the shop and the degree of warp ascertained by measurement. Its exact condition between the locking of the jacket and the first attempt to move this is not known. The present warp of the axis between the breech end and the support near the muzzle end of jacket is 0.1855 inch, and from here to the muzzle end of the gun, 0.1561 inch in the opposite direction but in the same plane. Between the first and second attempts at removal there was no noticeable variation of result. The interior diameter of the bore within the

jacket has been decreased as might be expected; but this decrease is quite irregular, reaching a maximum of 0.064 inch about two feet from the upper, or muzzle, end of the jacket, while at the other end of the jacket it is 0.017 inch. The diminution of bore extends to the extremity of the breech beyond the region of compression due to the jacket.

The only hypothesis upon which these irregularities can be even tentatively explained is lack of homogeneity in open-hearth steel. The better the steel the more nearly perfectly does it recover from strain after the removal of stress. Irregularity in heating during the first attempt would have produced warping in any metal whatever. Perfectly homogeneous steel would have recovered completely when the temperature became uniform, but any lack of homogeneity implies a permanent set. Assuming such lack, the larger the scale of experiment the more difficult it is to secure uniformity of temperature. The steel may satisfy completely the demands of preliminary test experiments on elastic limit and tensile strength, yet it may fail to meet the requirements of accurate fitting and complete recovery after wide variation of temperature. Krupp, with his admirably homogeneous but high priced crucible steel, has already been successful in assembling the parts of guns twice as massive as the recent subject of experiment at Watervliet. It remains to be seen whether equal success will be possible by the use of open-hearth steel in connection with the 16-inch gun yet to be constructed. In the light of recent difficulties the approaching work will be watched with interest.

The publication of these observations in the present form would not have been possible but for the friendly courtesy of Major Isaac Arnold, Jr., the commandant of the Watervliet Arsenal, who has granted me the utmost freedom of access to the gun shops and who kindly invited my interest and cooperation in the attempt to solve the problem of the unmanageable jacket.

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ONTOGENIC AND PHYLOGENIC VARIATION.

IN an article published in 1894, in Merckel u. Bonnet's *Ergebnisse der Anatomie u. Entwicklungsgeschichte*, the writer proposed the distinction which forms the title of this article. This subject was further elaborated in three papers before the Biological Section of the New York Academy, in March, April and May, 1896. As Prof. C. Lloyd Morgan and Prof. J. Mark Baldwin have quite independently reached somewhat similar conclusions, it seems of interest to publish the second and third papers, above referred to, in their original form as they were mailed to the Secretary of the Academy. These papers, by an unfortunate oversight, were never sent to the printers. The first paper was published in the *Transactions* and abstracted in SCIENCE.

The title of the paper of April 13th was 'A Mode of Evolution requiring neither Natural Selection nor the Inheritance of Acquired Characters.' It was discussed by Prof. Baldwin and Prof. Cattell. "I present a continuation of the subject of Ontogenic and Phylogenic Variation, discussed at the last meeting of the Biological Section. The latest papers upon selection are significant because they show that the hypothesis of evolution purely by the selection of fortuitous variations is losing ground. Definite or determinate variation is now admitted by nearly all writers except Wallace. If we assume the transmission of acquired characters the explanation of definite variation becomes simple enough, but in this contribution I propose a view of the facts which does not assume the transmission of acquired characters nor the im-